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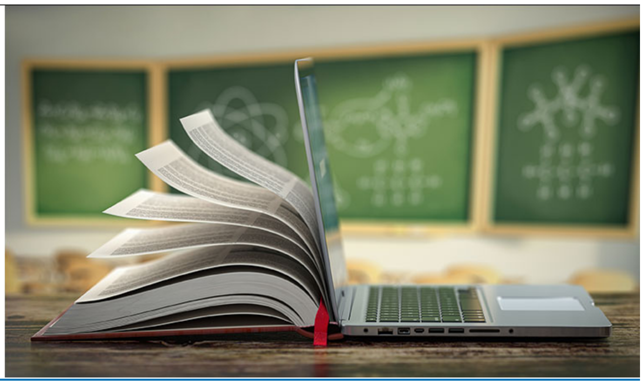

Simulation of the steelmaking process using collision avoiding cranes moving models

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Abstract. The paper discusses a steelmaking process and its optimisation using simulation. The optimisation goal is to reduce the total distance travelled by cranes in all spans as well as to reduce the steel waiting time before casting on a continuous casting machine. Models of the process under study have been developed in the AnyLogic simulation software and the modelling subsystem of the metallurgical enterprise automated system. A comparative analysis of the simulation results has been conducted. All results are feasible in terms of meeting the technological constraint on the steel downtime in front of the continuous casting machine for no more than 15 minutes. When comparing two collision avoiding cranes moving models, a choice has been made in favour of a model that provides cranes movement to the nearest steel processing aggregate. Using this model allows to reduce the total path travelled by cranes by 6%. The results of using different modelling systems are consistent.

1. Introduction

According the scale of metallurgical production, any opportunity to optimise the steelmaking process gives a tangible financial effect, reduces the cost of production by reducing waste, improves production quality or increases the efficiency productivity. One of the ways to improve the enterprise efficiency is to optimise the operation of cranes in the converter production. The optimisation goal is to reduce downtime for steelmaking before casting on continuous casting machine (CCM). Steel downtime leads to the need for additional heating of the melts in the after-furnace processing aggregates before casting on the CCM and equipment readjustment, which increases costs and reduces product quality. Another optimisation goal is to reduce the total path travelled by the cranes to reduce energy costs for the cranes servicing. Collisions of the cranes are not allowed.

The studied steelmaking process is a part of the complex multi-parameter system including technological processes of steel processing on the aggregates according to the technological route and the logistic processes of the steel moving between the aggregates. To analyse and optimise the processes of this system, it is advisable to use computer modelling. We consider the use of simulation for these purposes.

2. Literature overview

Use of simulation to solve the problem of analysis and optimisation of the bridge cranes movement in the steelmaking process is a promising area [1]. In the studies [1–5], discrete event simulation is used to analyse ongoing processes over time; additional heuristic algorithms are used to control the movement of the cranes without collisions. The optimisation goal is either to reduce the total lead time of a series of orders [1,3,5], or to reduce the total path travelled by the cranes [2,4]. In the studies [4,5], a hybrid genetic algorithm is used as a heuristic algorithm for controlling the cranes movement. A separate chromosome of the genetic algorithm encodes the assignment of the cranes on the existing orders; chromosome quality (fitness function) is evaluated using simulation. In the study [1], hybrid modelling is applied based on the integration of the Pert network planning method and simulation. First, reverse modelling is used to calculate the latest times of the beginning and end of processes, and then direct modelling is used to estimate the time of cranes movement between the aggregates. In the studies [2,3], the concepts of an active and passive crane are used: the active crane continues to move in the event of a conflict, the passive crane either stops or rolls away in the direction opposite to the movement of the active crane. Assignment of the active and passive cranes is carried out dynamically depending on the priorities of the transportation orders. In the study [2], the priority of the current order is applied and, in the study, [3] the priorities of the current and next orders are applied.

The main problem arises in the analysis of steelmaking processes is the need to optimise the logistic processes for the steel movement taking into account technological constraints imposed on the steel temperature and the time spent by steel at each stage of the technological route. None of the studies analysed took into account these technological constraints. Topical is the use of simulation to analyse steelmaking processes using collision avoiding cranes moving models and taking into account technological constraints on the time that melt spent before casting on the CCM.

3. Problem formulation

We consider the steelmaking process. The analysed aggregates include: three converters (BOF), three metal finishing devices, two steelmaking aggregates, two ladle furnaces, five CCM, six steel ladle cars, and five cranes. The mutual arrangement of the aggregates and vehicles, the paths of the steel cars, distribution of the cranes by spans, numbers of the steel cars and cranes are shown in Fig. 1.

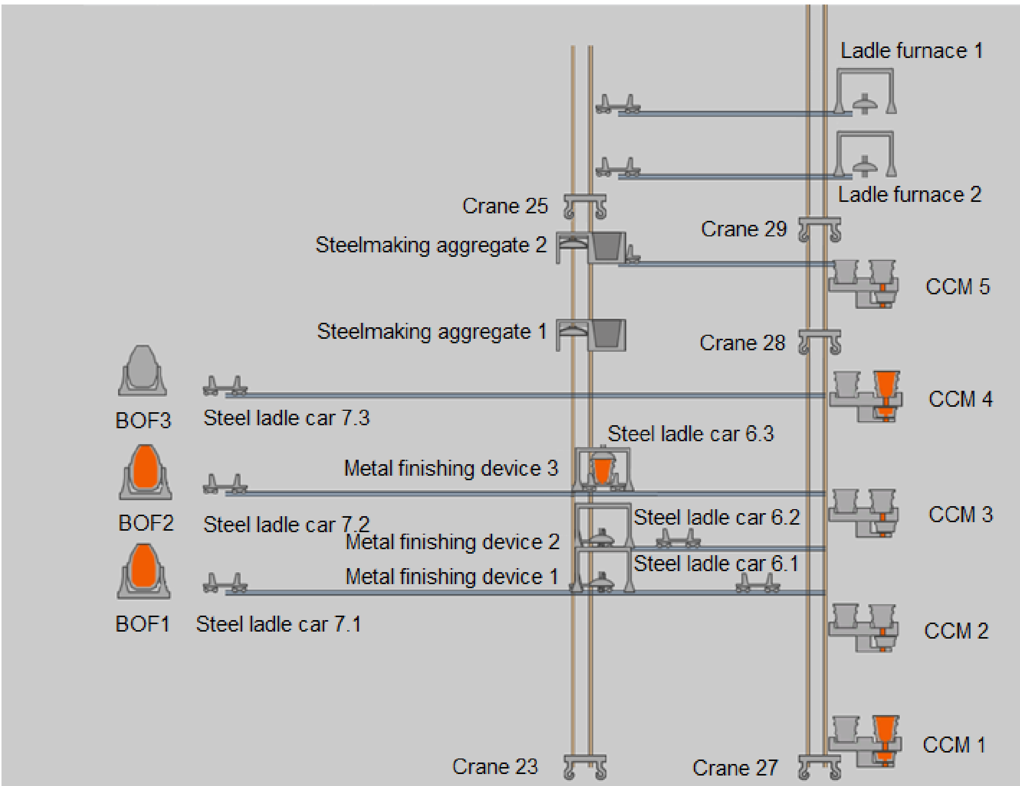

Figure 1. 2D visualisation of the steelmaking process with the layout of aggregates and vehicles.

The Fig. 1 is a view of the 2D visualisation window of the analysed processes with added notations in the metallurgical enterprise automated system [6,7]. Visualisation in the system is carried out both on the basis of real statistical data and on the basis of the results of process simulation.

The following cranes are involved in the melt moving along a specific span: cranes № 23 and № 25 for moving the melt between metal finishing devices and steelmaking aggregates; cranes № 27, № 28, and № 29 for transferring melt to one of the ladle furnaces and for casting on the CCM as well as removing empty steel ladles after casting. The melting process route always includes the following chain: BOF-metal finishing device-CCM. This route depending on the required chemical and physical properties of the steel can be expanded by additional processing of the melt before casting on the CCM at the following aggregates: steelmaking aggregate and (or) ladle furnace.

We consider two models of crane behaviour and evaluate the effectiveness of their application using simulation. Collisions between cranes are eliminated through the use of dynamic models of active and passive cranes. At a certain time, an active crane is a crane with remaining melt life time that is shorter than that of the other melts of the current span. The life time of the melt is set based on the technological requirements for the steel quality of the order.

The first behaviour model assumes that each crane serves aggregates strictly fixed to it: crane № 29 serves both the ladle furnace and the CCM № 5, crane № 28 – CCM № 4 and № 3, crane № 27 – CCM № 2 and № 1; crane № 25 serves both steelmaking aggregates, crane № 23 – three metal finishing devices. The second behaviour model assumes that the crane serves the aggregate depending on its current location and proximity to the aggregate requiring delivery.

We evaluate the effectiveness of the proposed models according to the following criteria: minimising of the total path travelled by the cranes and minimising of the downtime of the steel ladle before casting on the CCM. In case of exceeding the downtime of the steel ladle before casting a value of 15 minutes, it becomes necessary to heat the cooled steel in the ladle furnace, which entails additional energy wastage and decrease in the quality of products.

4. AnyLogic simulation

4.1. Simulation model development

The AnyLogic 7 modelling software has been chosen to simulate the steelmaking process [8]. There are examples of the development of the metallurgical processes models in this system [9]. In the AnyLogic, a simulation model has been built. When simulating the BOF work, the presence of competition for resources between units have been taken into account. For example, the “Purge” operation on the BOF cannot simultaneously go on more than two BOFs and therefore a resource “resProduvka” with a quantity of 2 units has been used. Fragment of the model 2 is shown in Fig. 2.

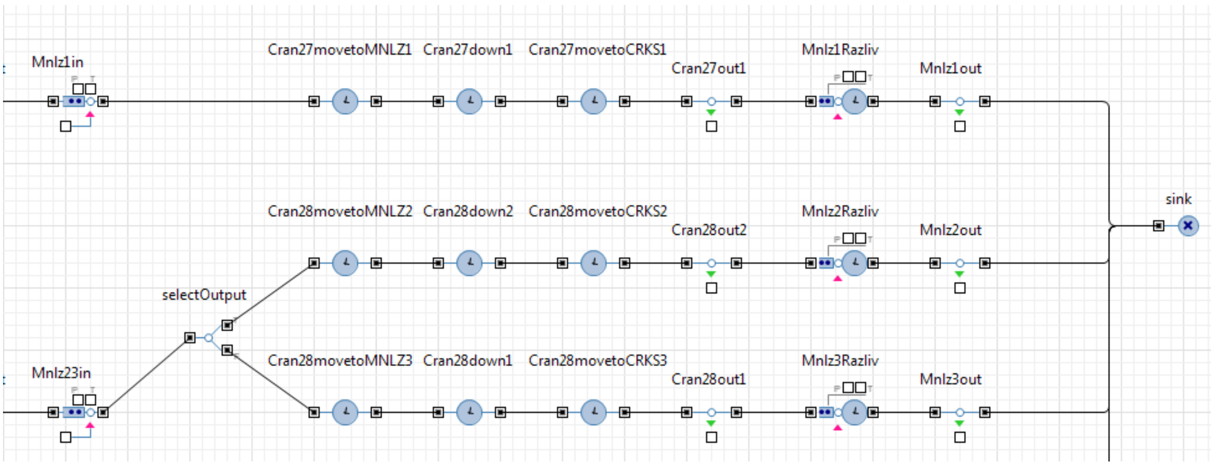

Figure 2. Fragment of the steel distribution from cranes № 27–29 on the CCM for model 2.

Model 1 – each crane serves aggregates strictly fixed to it. The aggregate is selected from the list of serviced in accordance with the selected order of priorities – if one aggregate is not available, the next aggregate from the set is selected, and so on. To simulate the operation of the CCM, two types of resources are used: the resource of the place to install ladles on the CCM (two resources per CCM) and the resource of the position (progress) of casting steel, one resource for each CCM. After installing the ladles on the CCM, the "Steel Casting" resource is captured; if there is a free resource, the steel spill operation begins in the service block. At the end of the casting, the resource “Steel Casting” and one place under the ladle on the CCM are released.

Model 2 – each crane serves the aggregate depending on its current location and proximity to the aggregate requiring delivery. The sequence of priorities for servicing cranes is determined by the proximity to the current point and the point of the “base” steel ladle.

4.2. Analysis of the simulation results
Two crane control models have been compared using experiments in the AnyLogic 7. Fragments of the total path travelled by each crane in the span of the CCM for models 1 and 2 are shown in Fig. 3.

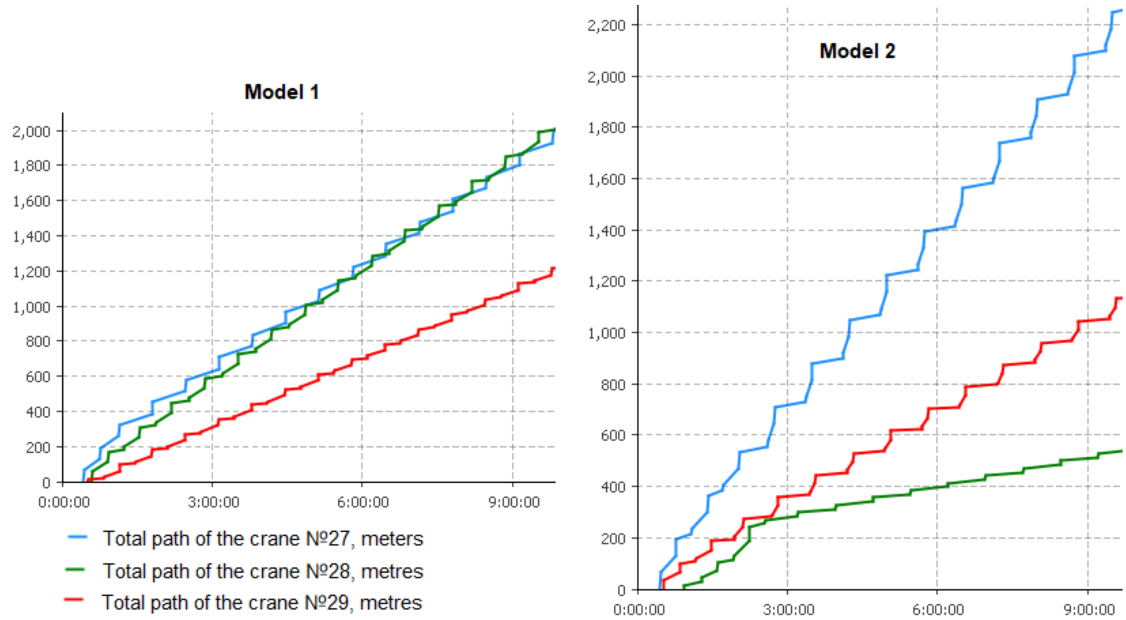

Figure 3. Fragment of dependence of the path travelled by the cranes on the simulation time.

When using model 2, the total volume of movement of the cranes from Figure 3 reaches about 3600 meters in 9 hours, which is less than the value of this indicator for model 1 (about 4700 meters in 9 hours). For both models, the critical downtime of the steel ladle before casting on the CCM is not exceeded 15 minutes.

5. Metallurgical enterprise automated (MEA) system simulation

5.1. Simulation model development
The model development has carried out in the module for creating models of the MEA-system using a notation of the multi-agent resource conversion processes [10]. The model is based on the previously developed model of the crane movement in the span before the CCM and steel casting on the CCM [7]. This model has been expanded by models of out-of-furnace processing aggregates as well as two analysed models of crane movement in the span after the BOF and the span before the CCM.

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Fragment of the model's structure that implements the movement of the cranes in the span in front of the CCM according to model 2 of the cranes control is shown in Fig. 4.

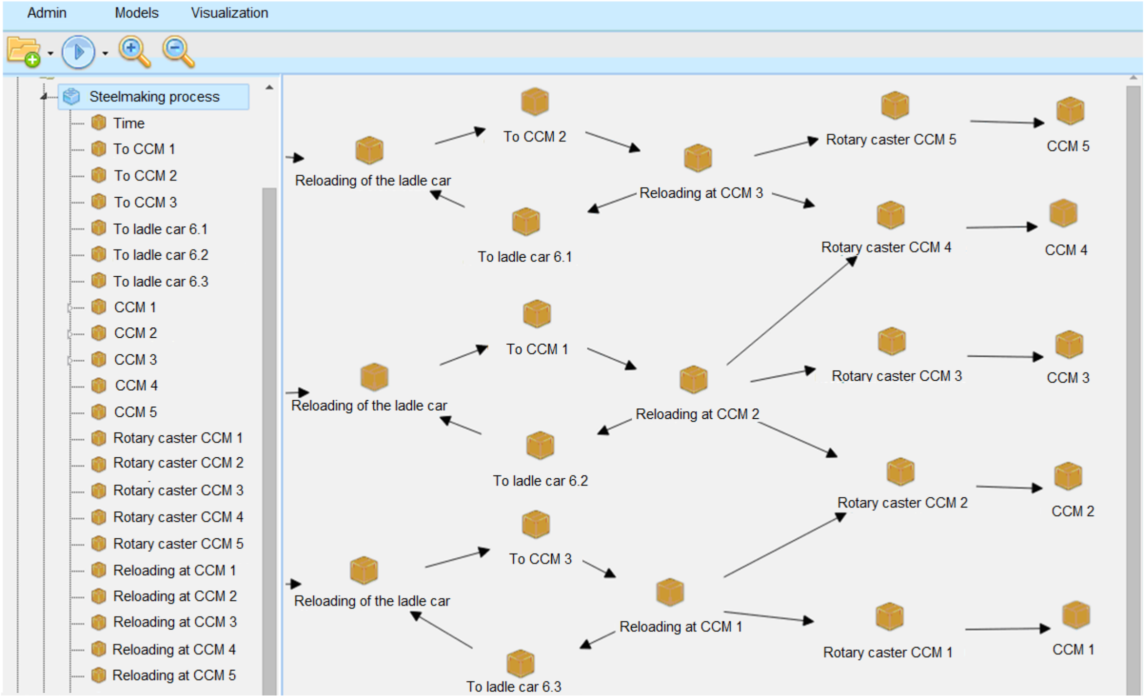

Figure 4. Fragment of the model's structure of the steelmaking process in the MEA-system.

2D process model has been developed (see Fig. 1). Agents in the model distribute cranes between aggregates. Operations in the model are used to visualise the duration of the order processing at the aggregates and the movement of vehicles. Six transactions are used in the model. Transaction *z*1 "Steel-ladle with metal" is the main transaction and is an order for melt casting on the CCM. Transactions *z*2, *z*3, *z*4, *z*5, and *z*6 "Crane 27", "Crane 28", "Crane 29", "Crane 23", and "Crane 25" are used to describe the operation logic of the cranes and to calculate the path travelled by the cranes. These transactions contain the following attributes: *dist* – accumulates the total path travelled by the crane, *location* – stores information about current location of the crane.

5.2. Analysis of the simulation results

Graphs of the total path travelled by the cranes in the span in front of the CCM are shown in Fig. 5.

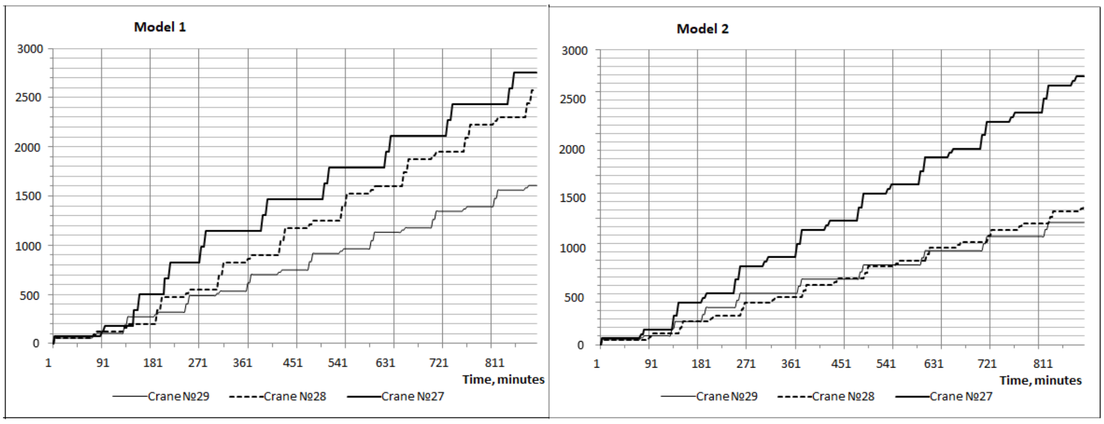

Figure 5. Graphs of the total path in meters travelled by the cranes in the span in front of the CCM.

With the developed crane movement model in the MEA-system, experiments have been conducted to analyse the efficiency of the crane movement models in terms of minimising of the maximum downtime of the steel ladle in front of the CCM and minimising of the total cranes path.

For both models, the maximum waiting time for casting ladles on each CCM did not exceed the critical value of 15 minutes.

6. Simulation results comparison

We compare the simulation results of the steelmaking process from the point of view of optimising the movement of cranes and taking into account the technological restriction on the downtime of ladles with steel before casting on the CCM. We compare the results obtained in the two modelling systems: AnyLogic and modelling subsystem of the MEA-system – for the two analysed collision avoiding cranes moving models. Comparative analysis of the simulation results is given in table 1.

Table 1. Comparative analysis of the simulation results.

Output characteristics (24-hours simulation)	Model 1		Model 2	
	AnyLogic	MEA system	AnyLogic	MEA system
Path of the crane №23, meters	4277	4134	4282	3987
Path of the crane №25, meters	4024	3951	4267	3979
Total path of the cranes №23 и №25, meters	8301	8085	8549	7966
Path of the crane №27, meters	4610	4350	5112	4561
Path of the crane №28, meters	4607	3995	1964	2325
Path of the crane №29, meters	2833	2663	2743	2445
Total path of the cranes №27, №28 и №29, meters	12050	11008	9819	9331
Total path of the all cranes, meters	20351	19093	18368	17297
Maximum steel ladle downtime before CCM (no more than 15 min)	9 min	10 min	7 min	9 min
Percentage by which the total crane path for the model 2 has decreased depending on the modelling system			6,2 %	5,8 %
Average percentage by which the total crane path for the model 2 has decreased across all modelling systems			6 %	

As follows from the analysis, both investigated models of the crane behaviour are acceptable from the point of view of satisfying the technological restriction on the waiting time for a steel ladle casting on the CCM. Application of the model 2 which involves servicing the closest aggregate by the crane depending on the location of the crane allows to reduce the total path travelled by all the cranes, therefore reduce energy costs and increase the life of the cranes. The percentage of decrease when modelling the daily operation of cranes via model 2 is 6.2% when using the AnyLogic system and 5.8% when using the modelling subsystem of the MEA-system. The data obtained in different modelling systems are consistent with each other; the average percentage reduction in the total path travelled by all the cranes was 6% per day when using model 2 of the crane behaviour.

7. Conclusion

The paper considers the process of steelmaking taking into account the constraint imposed by technological processes and the optimisation of logistic processes associated with the movement of the bridge cranes. Application of simulation for the analysis and optimisation of the processes under study is considered.

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The models of the steelmaking process have been developed in the two simulation systems: AnyLogic and modelling subsystem of the metallurgical enterprise automated system. In each of the systems, two models of crane movement have been implemented, which differ in the algorithm for matching the crane and the steel processing aggregate. In each of the models, a collision avoiding cranes moving algorithm is implemented through the use of the concepts of active and passive crane.

Comparison of the considered models of the crane behaviour in the different modelling systems has been conducted. It is concluded that the crane behaviour model 2 is preferable, which involves servicing the closest aggregate depending on the location of the crane. Application of this model reduces the total path travelled by the cranes by an average of 6% compared with the results of using an alternative model, which implies strict fastening of the aggregate to the cranes. The simulation results in different modelling systems are consistent with each other and ensure that technological constraint met for the downtime of the steel ladle before casting on the CCM.

The aim of the further research is to expand the existing model with models of the behaviour of steel cars and technological constraints on the processing of the steel on out-of-furnace processing aggregates.

Acknowledgments

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